Search for a High Mass Electron-Muon Resonance in the ATLAS Detector at the LHC

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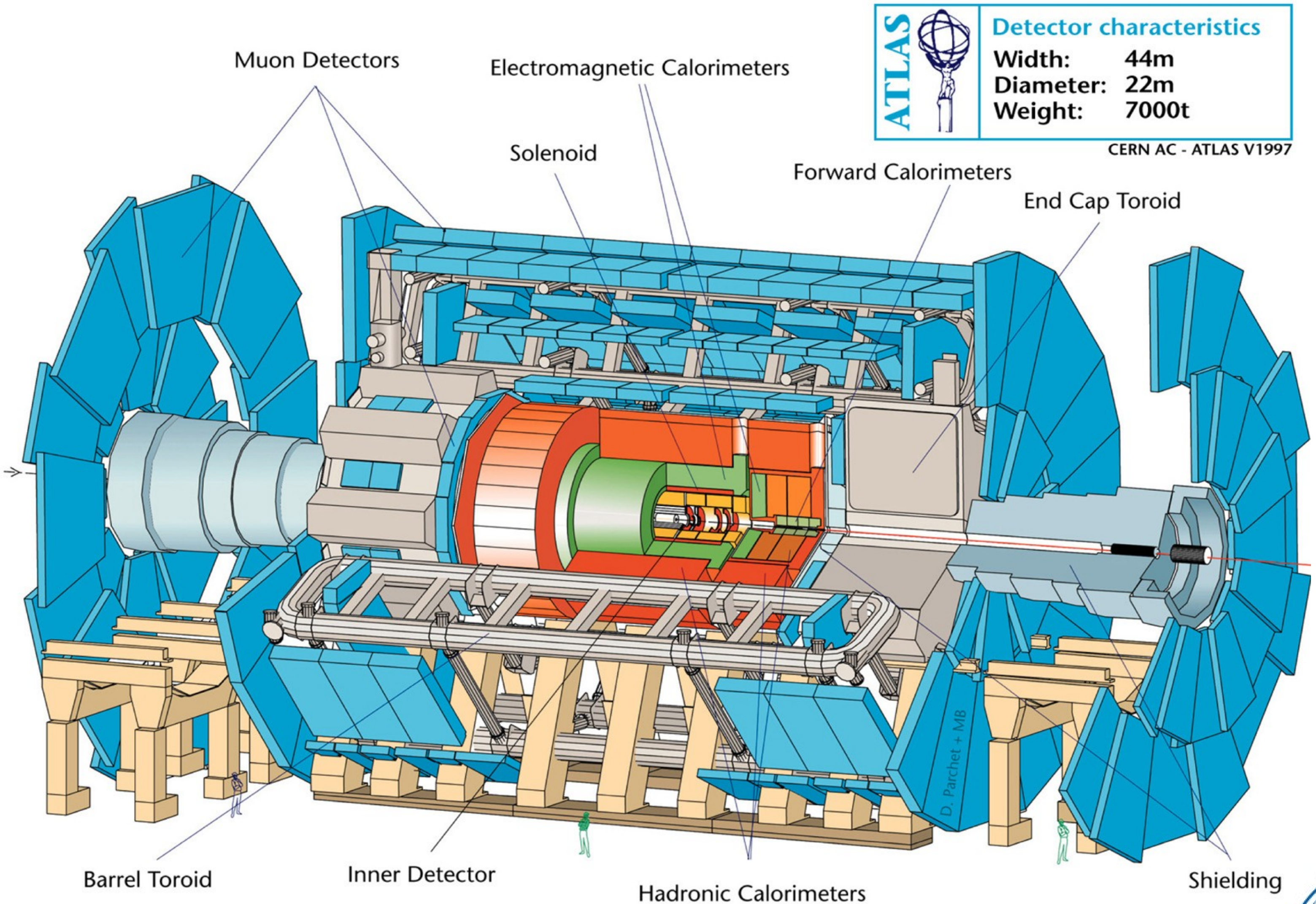
Outline

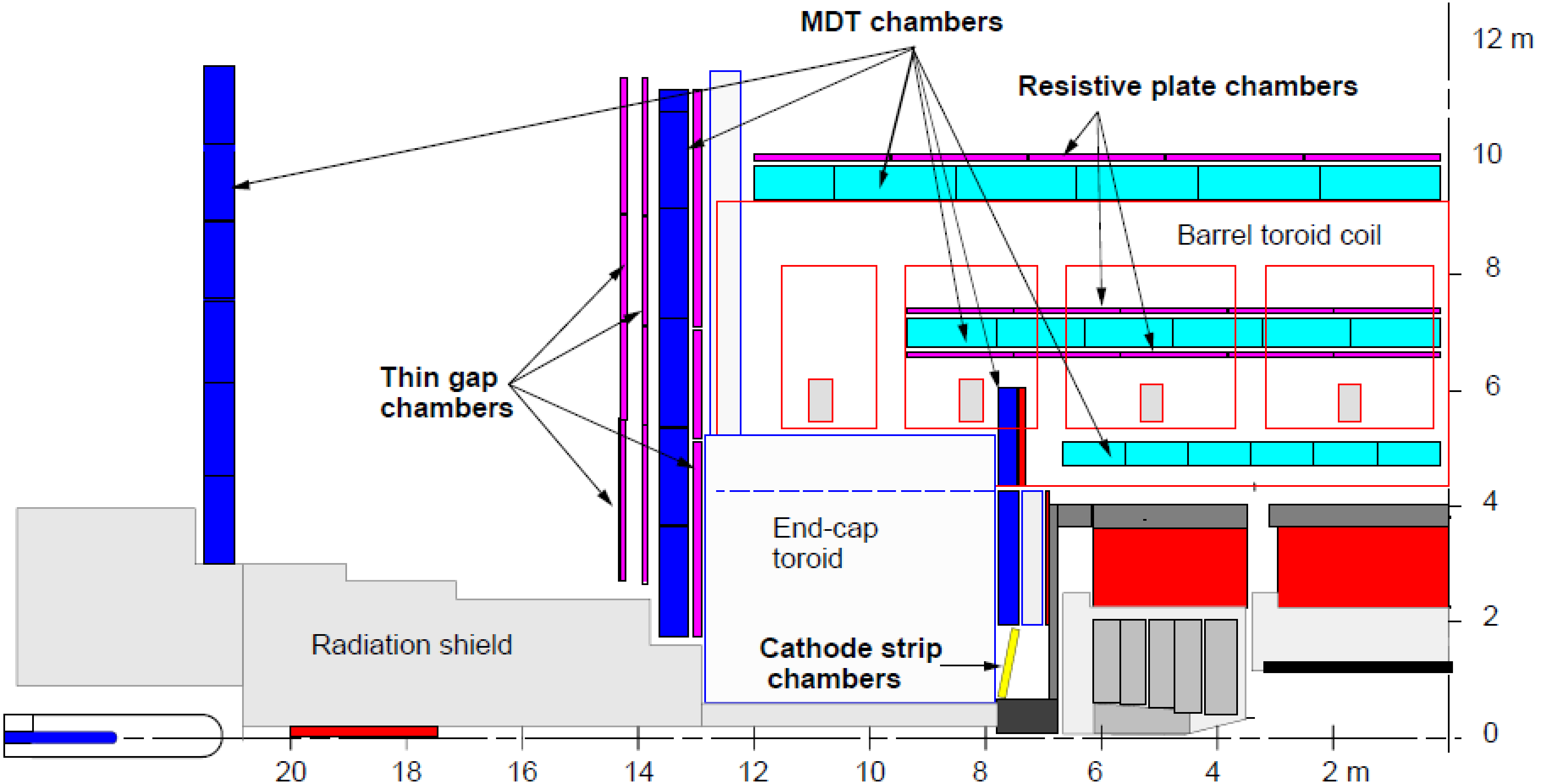
- LHC
- Detector
  - ATLAS summary
  - Muon Spectrometer
  - Alignment of the ATLAS MS
- Analysis
  - Theory/Motivation
  - Dataset
  - Event Selection
  - Backgrounds
  - Results

LHC

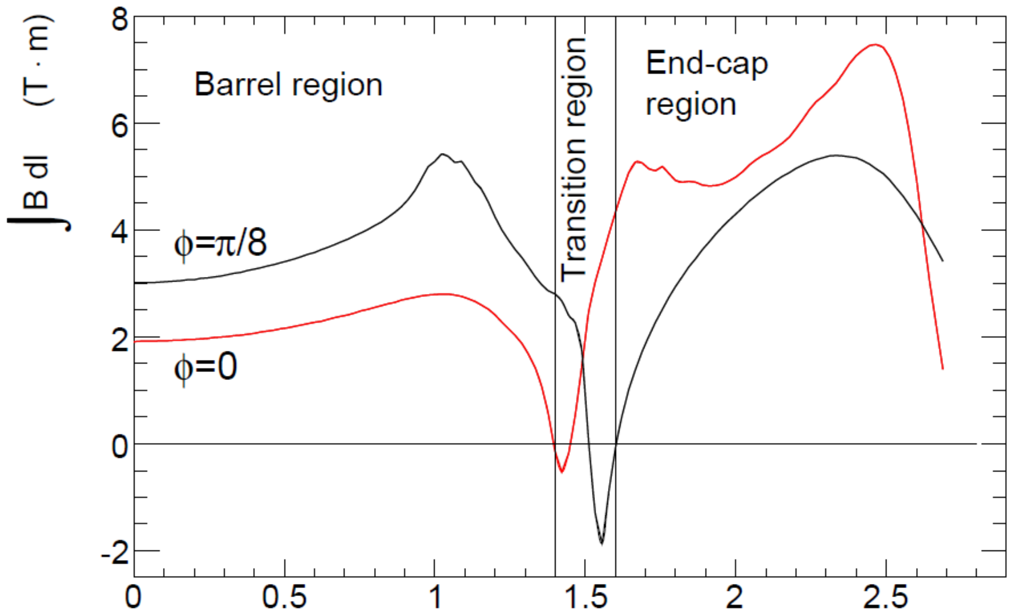
ATLAS

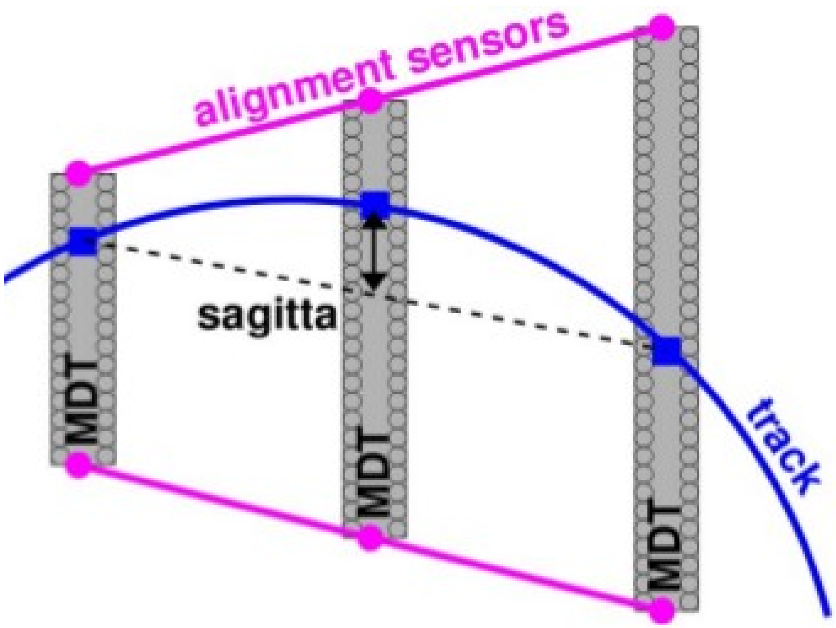

ATLAS
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding
D. Parchet + MB

ATLAS Muon Spectrometer

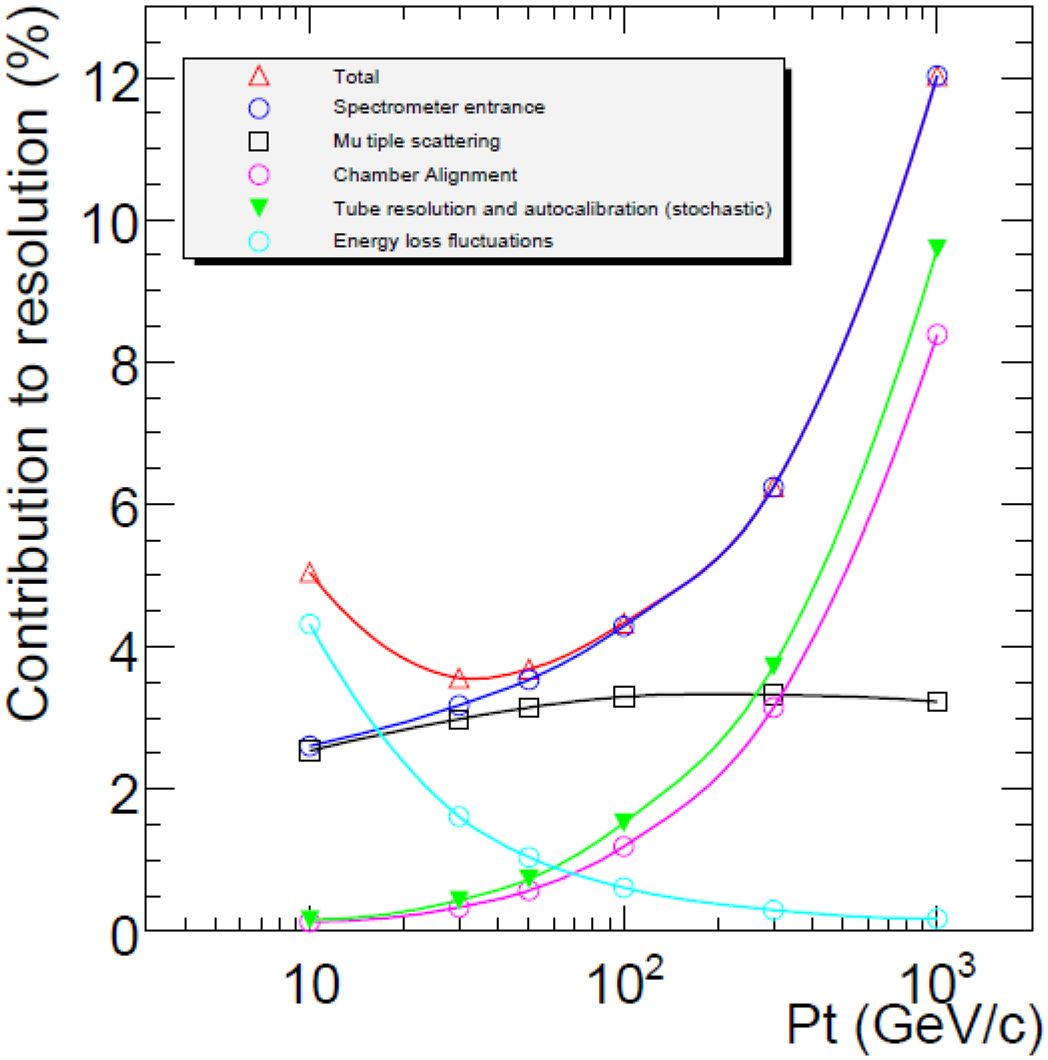


Muon Spectrometer B-Field





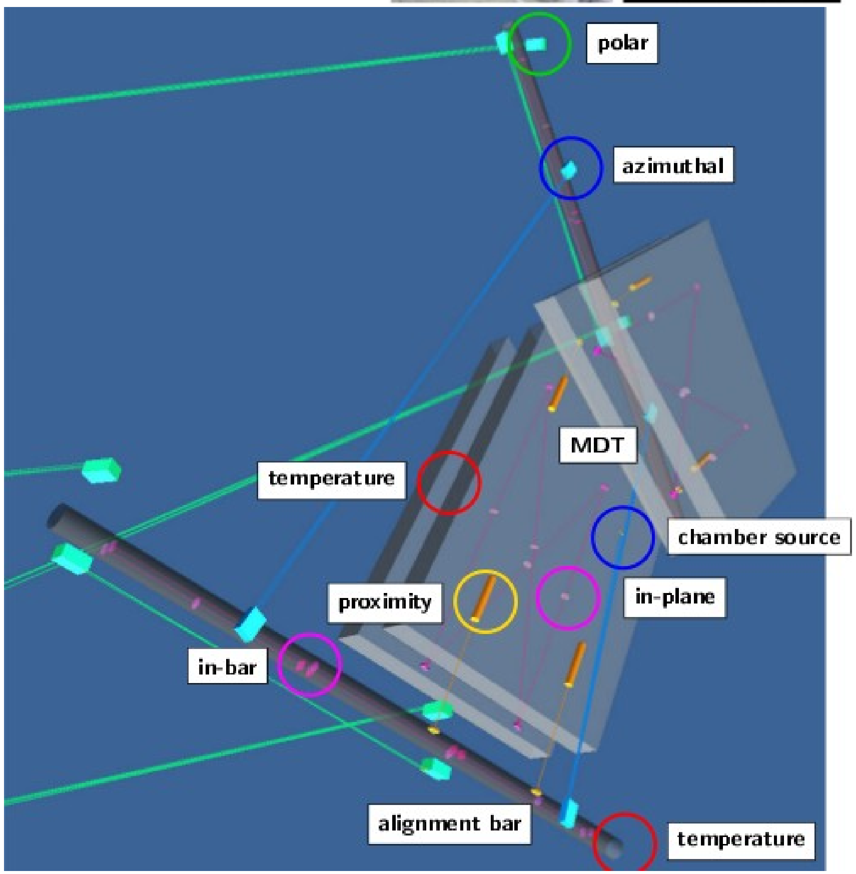
MS Resolution

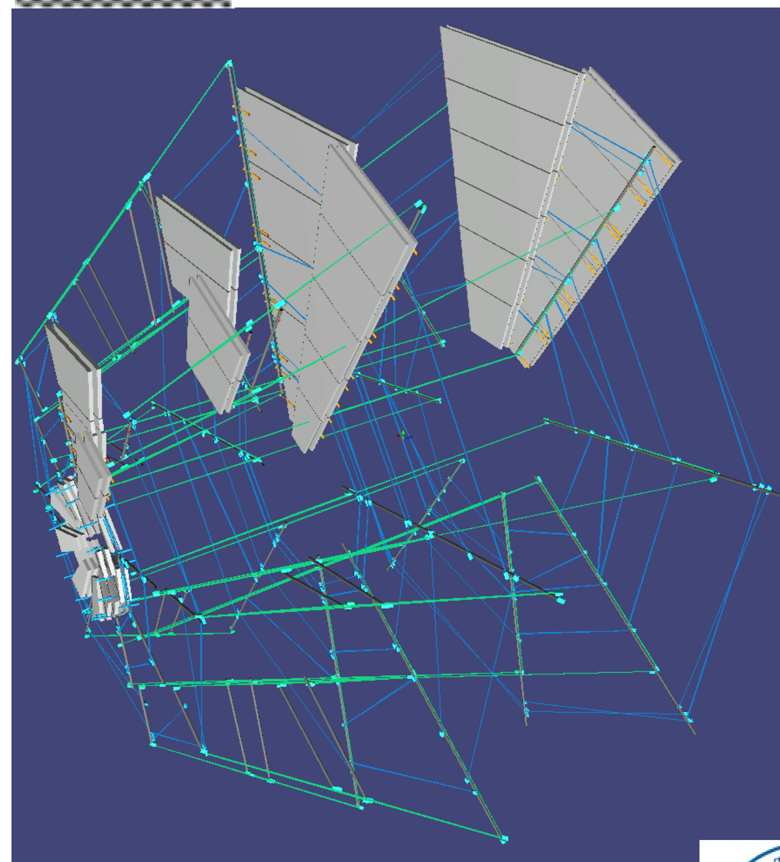


MS Alignment

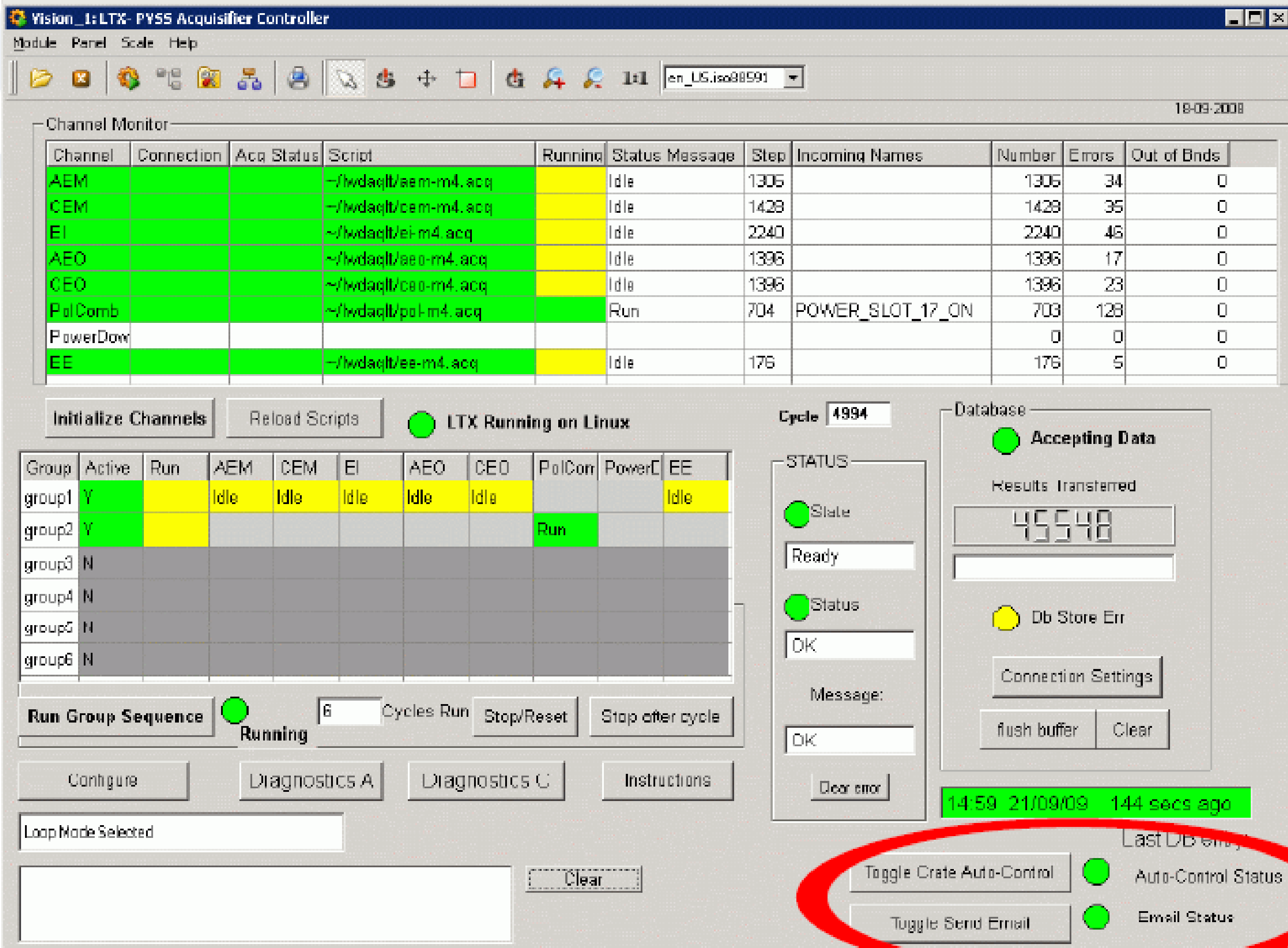
- Endcap and Barrel treated as separate subdetectors
- 2 general options to align detector
  - Relative Alignment
    - Precise initial alignment
    - Sensors monitor changes from initial
  - Absolute Alignment
    - Sensors used to calculate absolute chamber positions
- For various reasons, endcap chose absolute, barrel chose relative

MS Endcap Alignment





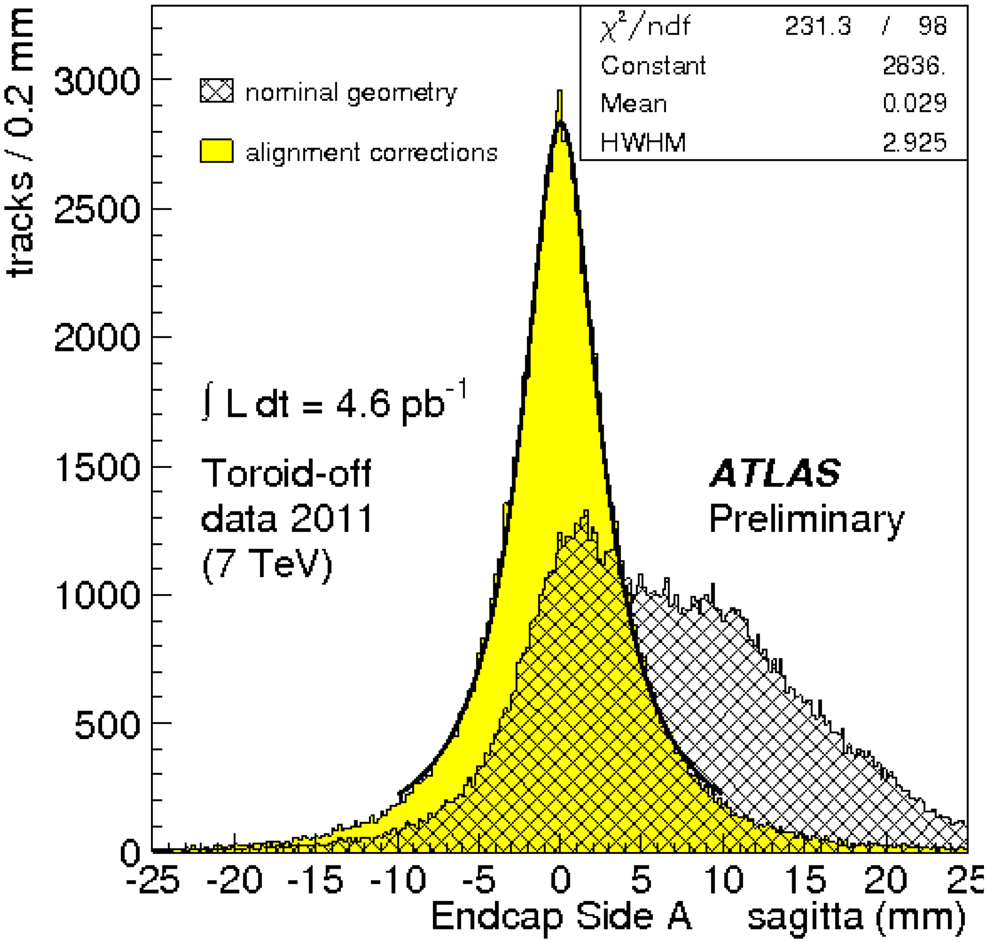
MS Alignment Software

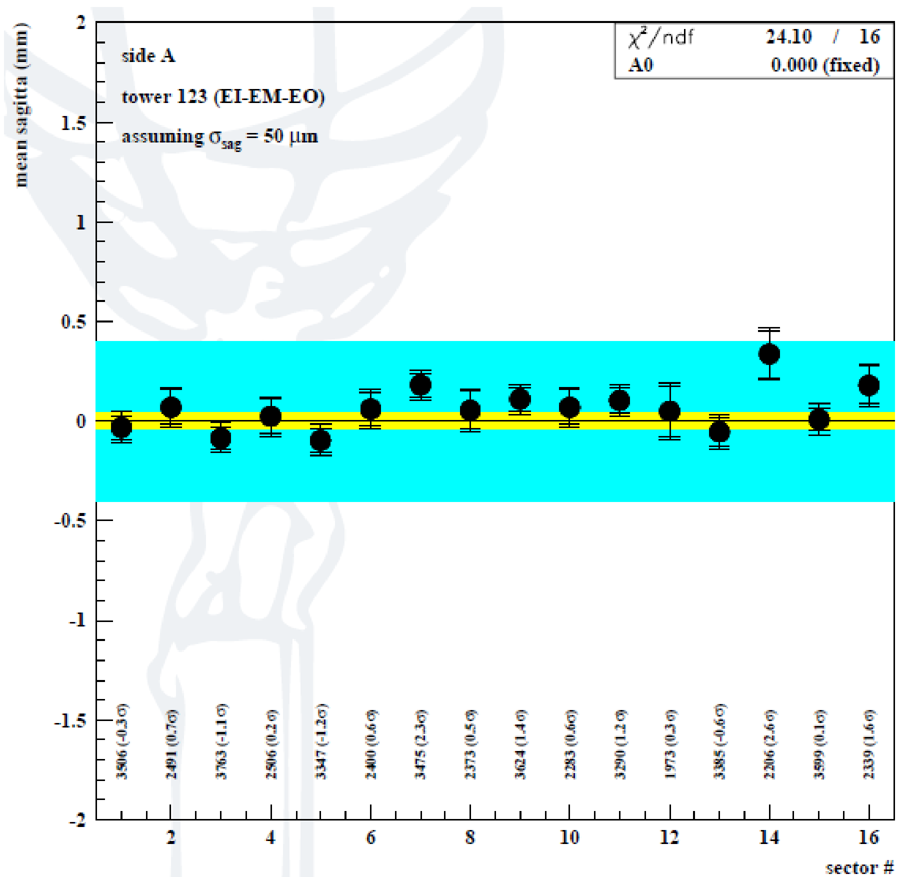


Alignment Validation - Strategy

- Use straight tracks to check alignment
  - Sagitta distribution centered at 0
  - Width dominated by multiple scattering
- Early 2011, ATLAS took ~5 pb^-1 of toroid off data
  - Millions of high momentum (p>25 GeV) muons
- Ancillary benefit
  - Possible to find non-alignment errors in MS

Alignment Validation - Results





Alignment Summary

- Alignment of the MS key to good momentum measurement
- Software running the sensors very reliable
  - Errors get flagged in ATLAS control room
- Validation using straight tracks
  - Near the desired 40 micron level
  - Several non-alignment issues discovered
    - Cabling errors
    - Incorrect chamber geometry
      - Spacer Height
      - Tube configuration
- Future: Using tracks to improve alignment

e-mu Resonance Motivation

- Lepton flavor conserved in SM
  - Result of accidental symmetry
  - To be renormalizable, operators must have mass dim<5
  - Processes with LFV have mass dimension >=5
- Non-renormalizable terms allowed if SM is weak scale approximation of higher energy model
  - Several theories allow for LFV (RPV SUSY, LRSM, etc)
- Neutrino oscillations confirm LFV
- Charged LFV would require new physics
  - Most searches for cLFV look for rare decays
    - mu->eee, mu->eγ, etc
    - Impossible at LHC
  - e-mu resonance most visible signature

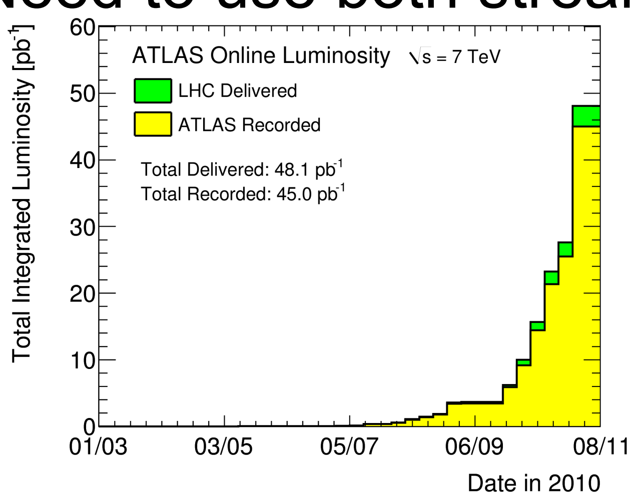
Benchmark Model

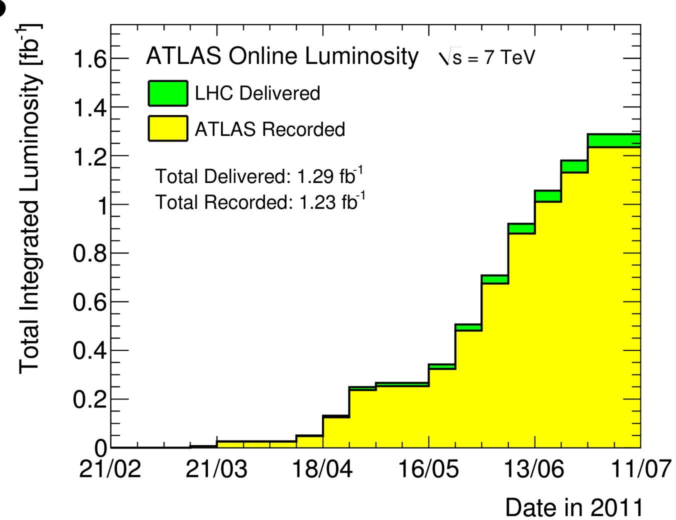
- Want to perform model independent search
  - Need basic model for signal simulation, limit setting
- Add LFV coupling to SSM Z', Q^{ℓ}_{12}
  - Not theoretically favored, but works as benchmark
  - Z'-e-mu coupling
  - Model would contribute to mu-> eee branching ratio
    - Set Z'-e-e coupling to zero to remove constraints

$$\sigma(q\bar{q} \to Z' \to l_i^- l_j^+) = \frac{g_z^2}{4\pi} \frac{(Q^l_{ij})^2}{144} \frac{M^2}{(M^2 - M^2_{Z'})^2 + M^2_{Z'}\Gamma^2_{Z'}}$$

Datasets/Triggers

- Analysis performed separately on 2010 and 2011 data
  - 2010 analysis: 35 pb^-1, PRL **106**, 251801 (2011)
  - 2011 analysis: 1 fb^-1, through July 2011
    - Accepted for publication in EPJC
- Signal events should pass both e and mu triggers
  - Requiring OR gives ~100% trigger efficiency
- Data separated by trigger stream
  - Need to use both streams





Backgrounds

- Physics Backgrounds
  - $Z/\gamma^* \rightarrow \tau\tau \rightarrow e\bar{\nu}_e\nu_\tau\mu\bar{\nu}_\mu\nu_\tau$
  - WW, ZZ, WZ
  - $q\bar{q} \rightarrow g \rightarrow t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow e\mu jj$
  - $gb \rightarrow b \rightarrow tW^- \rightarrow W^+be^-\bar{\nu}_e \rightarrow \mu^+\nu_\mu je^-\bar{\nu}_e$
- Instrumental backgrounds
  - QCD production, W/Z+jets, W/Z+γ
    - Jets can contain electrons or muons
    - Jets can be incorrectly reconstructed as electrons
    - Photons can be incorrectly reconstructed as electrons
    - Most of these events have one prompt lepton and one non-prompt
      - » Some contribution from events with two non-prompt leptons

Object Selection

- Searching for high-mass events, but need to confirm data-MC agreement at low-mass (high-background)
  - pT thresholds determined by trigger
- Electron
  - pT > 25 GeV
  - Track matched to calorimeter cluster
  - Shower shape requirements
  - Isolated (ET_cone < 10 GeV)
- Muon
  - pt > 25 GeV
  - Track in both MS and ID
  - ID track hits in all subdetectors
  - Isolated (pT_cone <10GeV)

Event Selection

- Require exactly 1 e 1 mu passing object selection
  - Opposite charge
- Event must pass trigger
- All relevant parts of the detector in working order
  - Some bad regions of calorimeter
    - Electron in such a region vetoed event
  - Calorimeter bursts vetoed event

Instrumental Background

- Estimated from data using “matrix method”
  - Loosen selection to get larger sample
    - Remove isolation requirements
    - Every event assigned a weight containing:
      - » Probability it would survive full selection
      - » 1-(Probability it contains two prompt leptons)
  - Background built from these weights
- Measure efficiencies from “clean” samples of prompt (Z decays) and non-prompt (dijet) leptons

$$\begin{bmatrix} N_{TT} \\ N_{T\bar{T}} \\ N_{\bar{T}T} \\ N_{\bar{T}\bar{T}} \end{bmatrix} = \begin{bmatrix} \epsilon_e \epsilon_\mu & \epsilon_e f_\mu & f_e \epsilon_\mu & f_e f_\mu \\ \epsilon_e(1-\epsilon_\mu) & \epsilon_e(1-f_\mu) & f_e(1-\epsilon_\mu) & f_e(1-f_\mu) \\ (1-\epsilon_e)\epsilon_\mu & (1-\epsilon_e)f_\mu & (1-f_e)\epsilon_\mu & (1-f_e)f_\mu \\ (1-\epsilon_e)(1-\epsilon_\mu) & (1-\epsilon_e)(1-f_\mu) & (1-f_e)(1-\epsilon_\mu) & (1-f_e)(1-f_\mu) \end{bmatrix} \begin{bmatrix} N_{PP} \\ N_{P\bar{P}} \\ N_{\bar{P}P} \\ N_{\bar{P}\bar{P}} \end{bmatrix}$$

Background Summary

Process	Number of Events (2011)
$Z/\gamma^* \to \tau\tau$	751±62
$t\bar{t}$	1578±173
WW	380±31
Single top	154±16
WZ	22.4±2.3
ZZ	2.48±0.26
$W/Z+\gamma$	82±13
Instrumental background	1175±124
Total background	4145±248

Signal Simulation

- Signal process does not exist in standard generators
  - Modified Pythia Z' ->ee and Z'-> mu mu
  - Changed flavor of one of outgoing particles
  - Gives both charge states ($e^{+}mu^{-}$ and $e^{-}mu^{+}$)
  - Branching ratio set to equal Z'-> mu mu branching ratio
- CDF set limits on similar models up to ~750 GeV (2006)
  - Later CDF/D0 results can be interpreted for this model
  - New interpretation gives limits up to ~900 GeV
- Chose to generate samples starting at 700 GeV

Signal Excpectation

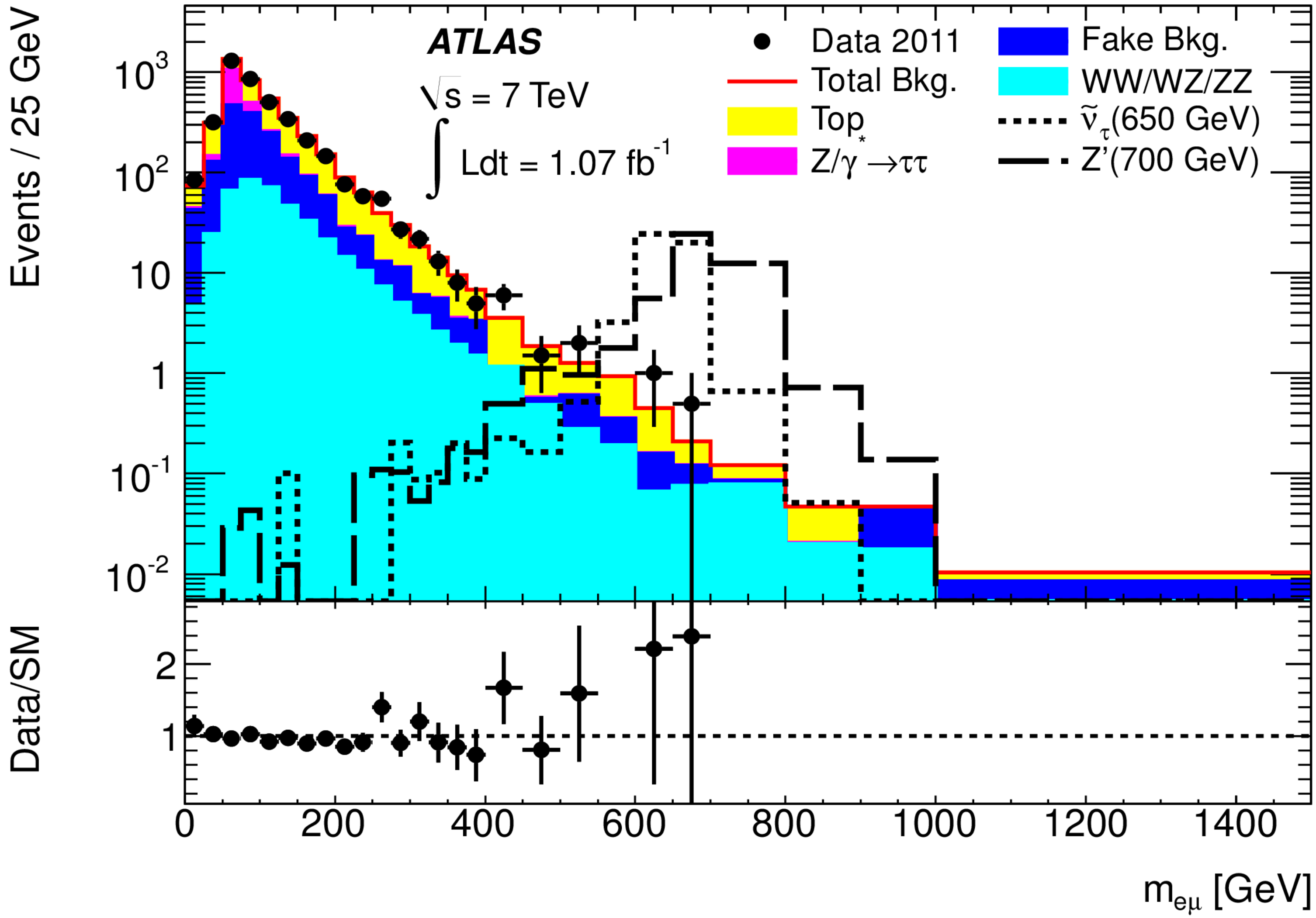
– Broad mass windows defined for each mass point

Mass (GeV/c^2)	Min. $M_{e\mu}$(GeV/c^2)	Max. $M_{e\mu}$(GeV/c^2)	Exp. Background
700	550	850	2.8$\pm$1.7
800	600	1000	2.3$\pm$1.5
900	700	1100	1.2$\pm$1.1
1000	750	1250	0.6$\pm$0.8
1500	1100	1800	0.04$\pm$0.19
2000	1600	2400	0$\pm$0

– Cross-sections and expected yields

Mass (GeV)	$\sigma \times BR$ (fb) LO*	Efficiency	Exp Events
700	551	0.594	327
800	315	0.610	192
900	186	0.610	113
1000	102	0.614	63
1500	10.6	0.610	6.5
2000	1.54	0.592	0.9

Results



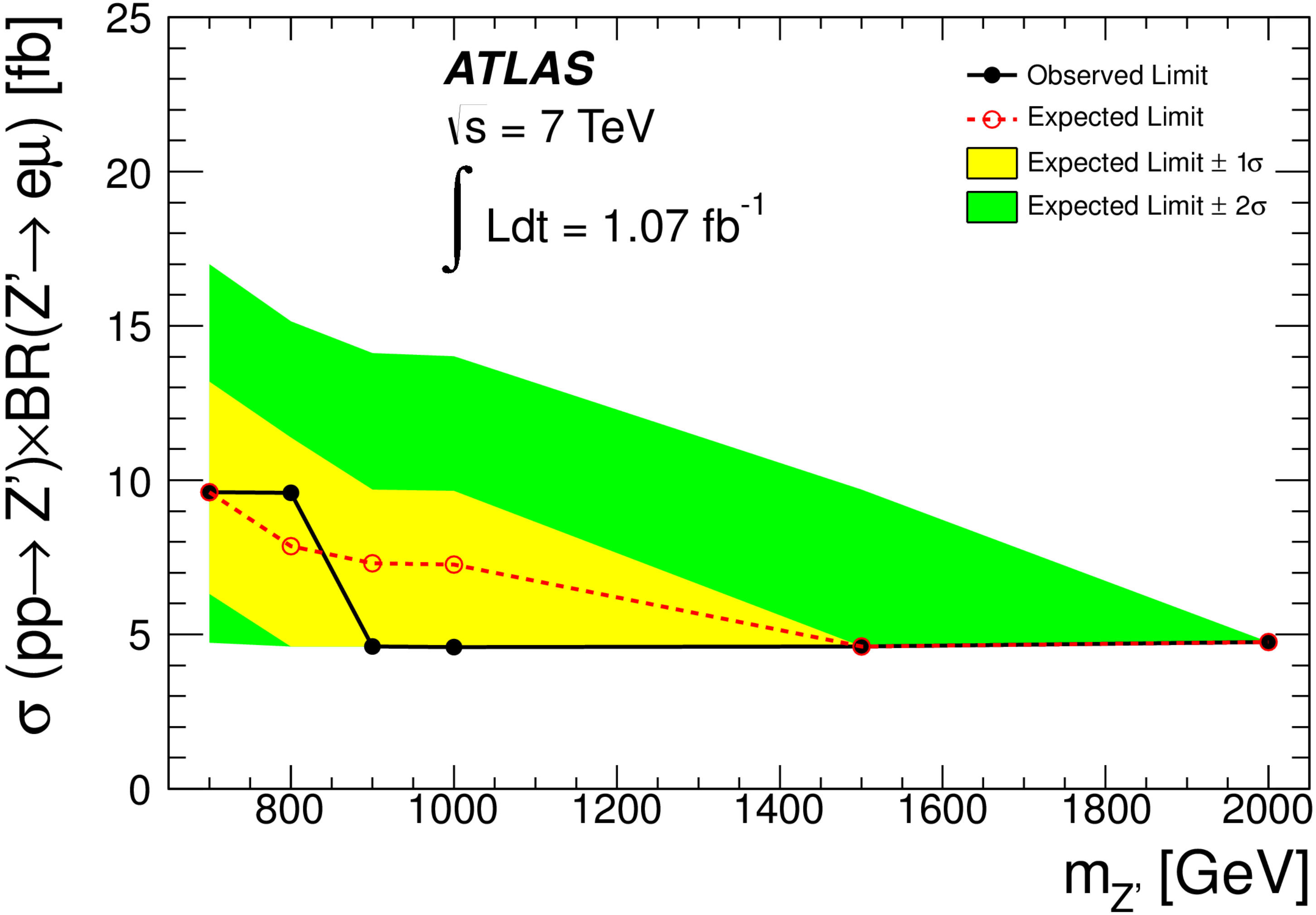
4053 events in data, 4145±248 predicted background

Limit Setting

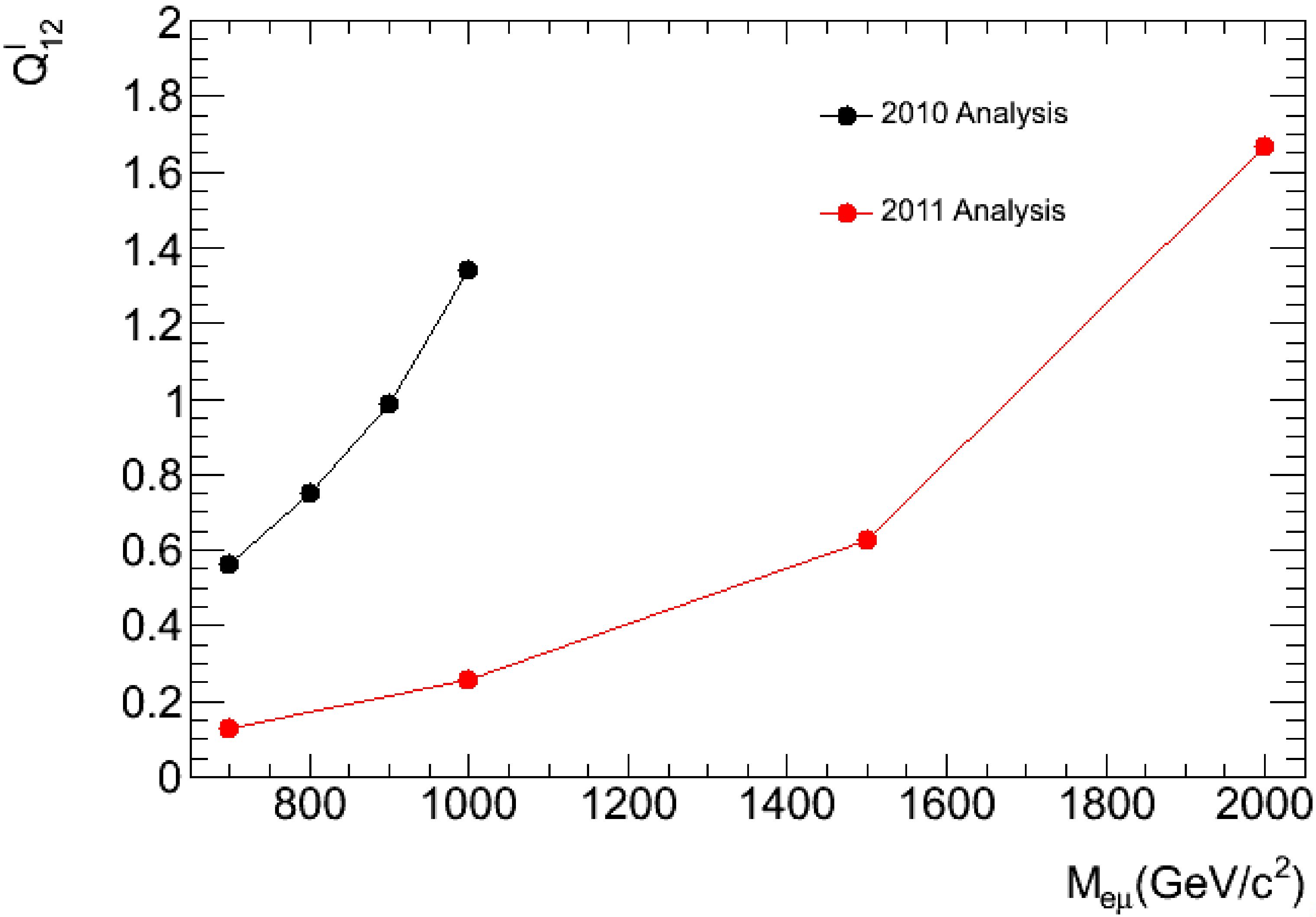
- Use Bayesian method to set 95% CL limits on cross section times branching ratio
  - Cross section proportional to $\left(Q_{12}^{\ell}\right)^2$
  - Limits can be set on coupling, as well
- Efficiency, luminosity, and background treated as uncorrelated nuisance parameters
  - Systematics:

Source	Fractional uncertainty (%)
2010 (2011) Luminosity	11% (3.7%)
Trigger efficiency	1%
Electron reco and ID efficiency	2%
Muon reco and ID efficiency	0.9%
Instrumental Background (2011)	10.6%
$Z/\gamma^* \to \tau\tau$ cross section	5%
ZZ cross section	5%
WW cross section	7%
WZ cross section	7%
$t\bar{t}$ cross section	10%
Wt cross section	9%
$W\gamma$ cross section	10%
$Z\gamma$ cross section	10%

Cross Section Limits



Coupling Limits



Summary

- Performed a search for high mass e-mu resonance
  - No excess observed
  - Limits set on production cross-section times branching ratio for “generic” vector particle decaying to e mu
  - Limits set on coupling for a benchmark model
- Limits set go beyond those presented by CDF
  - Higher mass range
  - Reinterpretation of later Tevatron results also do not reach same mass range
- Acknowledgements:
  - e-mu analysis team: D Pomeroy (Brandeis), D Zhang (Academica Sinica), J Zhu (U Michigan)
  - ATLAS collaboration
  - Advisor: Craig Blocker